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DYNAMICS OF NEAR - SHORE ICE

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I. SUMMARY OF OBJECTIVES, CONCLUSIONS AND IMPLICATIONS WITH RESPECT TO OCS OIL AND GAS DEVELOPMENT

The purpose of this project is to:

a. study the motion of the fast ice and near-shore sea ice north of Prudhoe Bay and in the vicinity of the Bering Strait,

b. make observations on major ice deformation features that occur near the edge of the pack ice/fast ice boundary,

c. explore the use of an air-borne pulsed radar system to measure the thickness of sea ice,

d. study the internal structure of near-shore sea ice,

e. characterize the spatial and temporal variations in *sea* ice pressure ridging via the use of laser profilometery and side-looking airborne radar (SLAR).

At the present time our results (discussed more fully later in this report) suggest the following:

a. during the time period March-May 1976 fast ice motions within the barrier islands are small,

b. fast ice motions outside the barrier islands increase with increasing distance from shore,

c. the fast ice/pack ice boundary may be located a considerable distance offshore from the 18 m. depth contour, where it is usually assumed to be located,

d. locally-formed multiyear pressure ridge systems are a major hazard to offshore development in water depths in excess of 18 m,

e. impulse radar *systems* can quite effectively obtain sea ice thickness information when operated from a helicopter,

f. large areas of fast ice may show the same crystal orientation (if this can be verified it may cause appreciable increases in the effective ice strength used to design offshore structures),

g. remote sensing studies of ice deformation show a general decrease in the amount of pressure ridging as one moves to the west from Barter Island and/or further north away from the edge of the fast ice.

II. INTRODUCTION

A. General Nature and Scope of Study.

The present program can be considered to be split into three main sub-projects:

1. The Narwhal Island Program

The purpose of this program is to obtain detailed quantitative information on the movement and deformation of both the near-shore pack ice and the fast ice along the coast of the Beaufort Sea (with particular emphasis on the region north of Prudhoe Bay). Using this same field site studies have also been carried out on the nature of the ridge systems located near the edge of the fast ice, on lateral variations in the thickness of first and multiyear ice, and on the internal structure of sea ice.

2. The Bering Strait Program

This program is focused on one task; measuring the flux of sea ice through the Bering Strait in specific and developing theoretical models for the motion of ice through straits in general.

3. The Remote Sensing Program

This program attempts both to gather remote sensing data using a laser profilometer, a SLAR system and standard mapping cameras and to utilize this data to study the nature of pressure ridging and ice conditions along the coast of the Beaufort and Chukchi Seas.

B. Methods and Field Sites

The Narwhal Island Program uses a radar ranging system that utilizes master units installed on 150 foot towers on Narwhal and on Cross Islands. These fixed master units range to remote transponders that are sited on the sea ice. This particular system was chosen because the very low elevations encountered along the coast of the North Slope greatly limit the range of more conventional radar systems. This information is also supplemented by precise strain measurements made using a laser ranging system. The targets in this case are corner reflectors sited on the sea ice at locations near Narwhal Island. The observations made on pressure ridge systems located near Narwhal Island have utilized conventional surveying, ice coring, and side-looking sonar systems. The ice thickness observations have utilized a GSSI pulsed radar system modified so that it can be operated from a helicopter. The studies of the structure of the sea ice in the vicinity of Narwhal Island have utilized conventional petrographic methods modified for ice.

We selected the Narwhal/Cross Island area of the barrier islands northeast of Prudhoe Bay because we believe it to be representative of the large number of barrier islands located north of the North slope. It is also an area of intense interest to oil companies. This makes our data both generally applicable to a type of environmental setting common along the edge of the Arctic Ocean as well as site specificications for certain leasing questions. Narwhal Island also has a number of logistic advantages because of the nearness of the Deadhorse/Prudhoe Bay complex.

The Bering Strait Program uses quite a different type of radar system to study ice motion through the Strait (i.e. a conventional marine X-band system with a P.P.I display. This system is effective at this location because the antenna can be sited on top of Cape Mountain at an elevation of

approximately 700 m. The data consists of time-lapse photographs of the radar screen on which the movement of the ice in the Strait can be observed. The resolution of this *system* is much less than the system used at Narwhal Island. However, this is not a problem because ice motions in the vicinity of the Bering Strait are very large. *Analysis* of the photographs will allow us to calculate the flux of ice through the Strait between Wales and Little Diomede Island. The radar data is also being supplemented using NOAA satellite data.

The selection of the Bering Strait as a study site was based on the fact that during the winter large amounts of sea ice stream through it from the Chukchi Sea into the Bering Sea. Therefore, understanding the nature of its ice conditions is essential to understanding the winter ice regimes in both the Bering and the Chukchi Seas and to some extent even in the Beaufort Sea. Also if there were an oil spill in either the Beaufort or the Chukchi Seas, the oil would move west within the ice until reaching the area north of the Straits. Then depending upon whether conditions favored the Straits acting as a "drain" for ice moving south or as a "block" the oil would move either south into the biologically rich Northern Bering Sea or north over the Pole exiting the Arctic Ocean east of Greenland.

The Remote Sensing Program primarily utilizes data obtained via a laser profilometer. This system is effective in studying the surface roughness of sea ice and is also relatively easy to operate under arctic conditions. These data are obtained on traverses oriented roughtly normal *to* the coast. Each traverse is 200 km long and the starting points are Barter Island, Cross Island, Lonely, Barrow, Wainwright and Point Lay. These points were chosen primarily because they are easy aircraft turning points and are spaced roughly evenly along the coast. The timing of the laser flights is arranged to

sample ice conditions representing the different seasons of the year (fall-winter-spring-summer). The SLAR coverage which has been flown by Fort Huachuka is less frequent and has been restricted to the summer and late winter periods. These flights have usually been made parallel to the coast.

c. Relevance to Problems of Petroleum Development

A knowledge of motion, deformation and physical characteristics of both the near-shore pack ice and the fast ice is essential to adequately designing and estimating the hazards associated with *a* variety of engineering options that may be considered for offshore operations in the near coastal areas of the Beaufort and Chukchi Seas (e.g. construction of gravel islands, structural platforms, causeways, reinforced ice platforms, buried pipelines, or the utilization of the ice sheet itself to carry large, long-term loads). The present program contributes directly to the solution of this general class of engineering problem in that it will provide much of the geophysical and engineering data upon which sound engineering and regulatory decisions can be made. The Narwhal Island area that is being studied is currently being considered by the petroleum companies because *it* possesses favorable geologic structures and is a natural extension of the known Prudhoe Bay field. Of all the Alaskan OCS areas it is one that will undoubtedly be developed in the very near future inasmuch as a transportation system is nearing completion (the Alyeska Pipeline) that will enable the operating companies to readily move any offshore *oil* south to existing markets.

Our interest in observing and in developing methods to predict the drift of pack ice through the Bering Strait is, as mentioned earlier, linked to the fact that ice flow through the Straits would be a key mechanism in dispersing an oil spill occurring along the coastal areas of the Beaufort and Chukchi Seas. We also believe that a knowledge of the ice

conditions in the Strait is essential to developing an adequate ice forecasting model for the Chukchi and Bering Seas. Such a model is required to predict the trajectories of potential oil spills.

The remote sensing program provides the basic information on the distribution of ice types and features and in particular ridges that will be required as one aspect of a risk analysis for the construction of an offshore drilling platform sited on the edge of the Arctic Ocean.

III. CURRENT STATE OF KNOWLEDGE

There has never been a comparable study of the motion of near-shore fast and pack ice as is being carried out at Narwhal Island. The closest study is that of the University of Washington (R.U. #98) using drifting data buoys employed on the ice north of the Alaskan coast. These buoys are located further offshore than our study area. However, this data set may ultimately prove to be useful to us in analyzing our results. The oil companies have also carried out studies of the motion of the fast ice in the vicinity of our operation. However, their results have not been made available to OCS program.

The Bering Strait Program is also quite different than existing programs. The most similar programs are R.U. 250 which uses a radar system to study the formation of near-shore ridges near Barrow, and the Japanese program using radar to study ice motion along the coast of Hokkaido. Neither of these efforts is focused on the problem of the passage of sea ice through restricted channels.

The laser profilometer program is the only such program currently uncle rway. In the past there have been laser flights in the area of the Mackenzie Delta carried out by the Beaufort Sea Program. This data will be most useful to us in making regional comparisons of ridging intensities.

IV. RESULTS

1. Published reports (DB indicates availability in the OCS Data Bank)

   a) Kovacs, A. (1976) Grounded ice in the fast ice zone along the Beaufort Sea Coast of Alaska. CRREL Report 76-32, 21 pp (DB)

   b) Kovacs, A. and Gow, A. J. (1976) Some characteristics of grounded floebergs near Prudhoe Bay, Alaska. CRREL Report 76-34, 10 pp (DB)

2. Reports Completed and In Press

   a) Weeks, W. F., Kovacs, A., Mock, S. H., Tucker, W. B. Hibler, W. D. and Gow, A. J.. (1977) Studies of the movement of coastal sea ice near Prudhoe Bay, Alaska. Journal of Glaciology, Vol. 19, No. 81 (DB, available in xerox copy only).

   b) Kovacs, A. (1977) Sea ice thickness profiling and under-ice oil entrapment. Offshore Technology Conference (DB, available in xerox copy only).

   c) Schwarz, J. and Weeks, W. F. (1977) Engineering properties of sea ice. Journal of Glaciology, Vol. 19, NO. 81 (DB, available in xerox copy only).

   d) Cow, A. J. and Weeks, W. F. (1977) The internal structure of fast ice near Narwhal Island, Beaufort Sea, Alaska. CRREL Report.

   e) Sohdi, D. S. (1977) Ice arching and the drift of pack ice through restricted channels. CRREL Report.

3. Reports in Preparation

   a) Kovacs, A. (1977) The origin of rock debris found on sea ice north of Narwhal Island, Alaska. CRREL Report.

b) Tucker, W. B.III, Weeks, W. F., Kovacs, A. and Gow, A.J., (1977) Near shore ice motion at Prudhoe Bay, Alaska. AIDJEX Sea Ice Symposium.

c) Weeks, W. F., Tucker, W. B. III, Frank, M. and Fungcharoen, S. (1977) Characterization of the surface roughness and floe geometry of the *sea* ice over the continental shelves of the Beaufort and Chukchi Seas. AIDJEX Sea Ice Symposium .

V CONCLUSIONS

A. Narwhal Island

a) Laser observations of fast ice motion at sites close to Narwhal Island show long term changes in the distance to targets located on the ice that are believed to be primarily the result of the thermal expansion of the sea ice. The main ice motion was outward normal to the coast (in the least-constrained direction). The maximum movement was approximately 1 m with short term changes of 30 m.

b) Radar observations of fast ice sites further off-shore from the barrier islands do not permit the study of small motions (as do the laser records) because of insufficient measurement resolution. However, these records show many larger events with the standard deviation of the motion measured parallel to the coast increasing systematically with distance off-shore reaching a value of ±6.6 m at 31 km. The ice motions show short term displacements of as much as 12 m at the sites furthest from the coast. The observations also show systematic changes in line length (up to 6 m over a distance of 30 km) that are believed to be the result of thermal expansion

of the ice. Correlations between the wind and the ice movement are only appreciable for movements normal to the coast.

c) Radar targets located within the pack ice showed large short term movements (up to 2.7 km) but negligible net motion along the coast. There was no significant correlation between the motion of the pack and the local wind suggesting the models for predicting coastal ice movement in the Beaufort Sea during the March-June time period can only succeed if they are handled as part of a regional model which incorporates the lateral transfer of stress through the pack ice.

d) Off-shore from Narwhal and Cross Islands the fast ice/pack ice boundary was usually located (during March-May 1976) in 30 to 35 m of water as opposed to 18 m of water where the boundary has been observed at sites further west along the Alaskan coast.

e) The large grounded multiyear shear ridge formations that were studied along Beaufort Sea coast in the Harrison Bay/prudhoe Bay area must be considered as formidable obstacles in the development of off-shore operations in this region. In the design of off-shore drilling structures significant consideration must be given to not only the forces which can develop when these formations are pushed against the structures, but also to the potential for ice piling Up and overriding them. The inner edges of the multiyear shear ridge formations studied north of Cross Island were found to be as high as 12.5 m and to be grounded along the ∿15 m depth contour. This depth is significantly less than the ∿19 m contour previously considered

to be the water depth at which grounded shear ridges begin to form. The grounded ice formations studied formed in the fall of 1974 and remained through August 1976. However, they were not present in November 1976.

f) The dual antenna impulse radar system was highly effective in determining the thickness of both first-year and multiyear sea ice from the air. Good agreement was achieved between calculated and observed ice thicknesses and representative cross-sections of both ice types were obtained. These cross sections reveal characteristic undulating bottom relief in both ice types which could trap significant amounts of oil as the result of an under-ice spill. Preliminary estimates of the entrapped volume of oil are 0.03 m^3 of oil per square meter of ice area for first year ice and 0.3 m^3 of oil per square meter for multiyear ice.

g) Our observations coupled with published U.S. and Russian results suggest that very large areas (tens of kilometers) of sea ice have sufficiently similar c-axes orientations to act as a large single crystal. If this proves to be the case off-shore structures may have to be designed for "hard-fail" ice strengths which are 2 to 6 times the strength values normally used. The Russian theory that such orientations are aligned parallel to the magnetic field is shown to be doubtful.

B. Bering Strait

a) The radar system was installed at Top Camp at Tin City on the Bering Strait and is now operating at 15 KW power output.

b) The theory of the flow of granular media through chutes and

hoppers has been applied with considerable success to ice motion through the Bering Strait. There is good correspondence between observed arching and lead patterns and those predicted by theory. In addition values determined via the theory for the angle of internal friction of pack ice ($\approx$ 30 to 35°) and the cohesive strength (%2000 N/m^3) are similar to values obtained by other approaches. It is estimated that if the wind velocity parallel to the Bering Strait exceeds $\approx$ 6m/s, there will be ice flow through the Strait.

c. Remote Sensing

a) During the 1975-76 ice season the heaviest ridging occurred at Barter Island and there was a general decrease in the intensity of the ridging as one moves further west into the Chukchi Sea. Ridging also decreases as one moves further" offshore. Individual frequency profiles fall off in an exponential manner as ridge height increases. There is no decrease in frequency at low ridge heights as has been suggested from the analysis of sonar profiles.

b) Analysis of SLAR imagery shows that the area of ridged ice decreases in a linear manner as one moves away (North) of the coast. There is no obvious break corresponding to the boundary of the so-called shear zone.

c) The most common shape of multiyear ice floes is roughly circular. The largest length to width ratio observed was just over 5. The distribution of floe diameters shows an exponential decrease as floe size increases. The largest floe diameter observed was 3600 m.

d) Although there have been many studies of the engineering properties of sea ice, there still is considerable uncertainty concerning the appropriate values to use in offshore design. This comment is particularly true of the mechanical properties where both the basic experimental measurements and their interpretation are not well resolved.

VI. SUMMARY OF 4th QUARTER OPERATIONS

During this quarter time has been devoted to the following three subjects:

A. Preparation for the 1977 Narwhal Island Program.

All field equipment has been shipped and as of 31 March 1977 Tucker, Weeks and Kelley are in the field.

B. Report Writing

The papers by Gow and Weeks and by Sodhi have been completed.

C. Installation of the X-band Radar System at the Bering Strait.

Frank and Weeks were in the field during most of the month of February completing this installation.

We currently estimate that we have expended one quarter of our funding.